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Drifter Trajectories in Riverine Environments

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LONG-TERM GOALS

The long-term goal is to understand the Lagrangian surface behavior in natural riverine systems by deploying a fleet of GPS-equipped drifters.

OBJECTIVES

The primary objective is to deploy NPS and QinetiQ GPS-equipped surface drifters in a number of natural rivers to describe dispersion and the spatially varying velocity field. The drifter observations will be compared to the underlying river morphology and compared with numerical models, such as Delft3D and USGS river models. Position tracking drifters offer a new perspective in describing flow characteristics in riverine environments that has been previously overlooked.

APPROACH

The approach is to:

1) deploy 20-40 GPS-equipped drifters over a number of reaches in Kootenai River, ID, Trinity River, CA, Klamath River, CA, Skagit River, WA, and Elkhorn Slough, CA,
2) perform data quality control, transform positions into local along- and across channel river coordinates, and estimate the velocity field and dispersion,
3) relate these observations to the river morphology and describe the drifter trajectories,
4) and compare these drifter observations to Delft3D and USGS models.

WORK COMPLETED

We (MacMahan, Swick, and Jon Nelson - USGS) have performed 6 drifter deployments over three different hydrodynamic reaches in the Kootenai River, Idaho (Figure 1). In addition, we deployed drifters in the Skagit River and North Fork in September 2009 as part of the ONR Coastal Geosciences Tidal Flat DRI. Results from the Skagit drifter deployments are discussed below. Additional drifter deployments in the Kootenai River, ID, Trinity River, CA, Klamath River, CA, and Elkhorn Slough, CA are planned for the fall of 2009.

MacMahan, Cowen, Swick, and Lambert built 20 riverine drifters, which are a modified design of the surfzone drifter by MacMahan et al. [2009]. We are currently building 20 additional riverine drifters for the fall deployments to increase statistical observations and to test different deployment schemes (Swick and MacMahan, 2009).

Report Documentation Page

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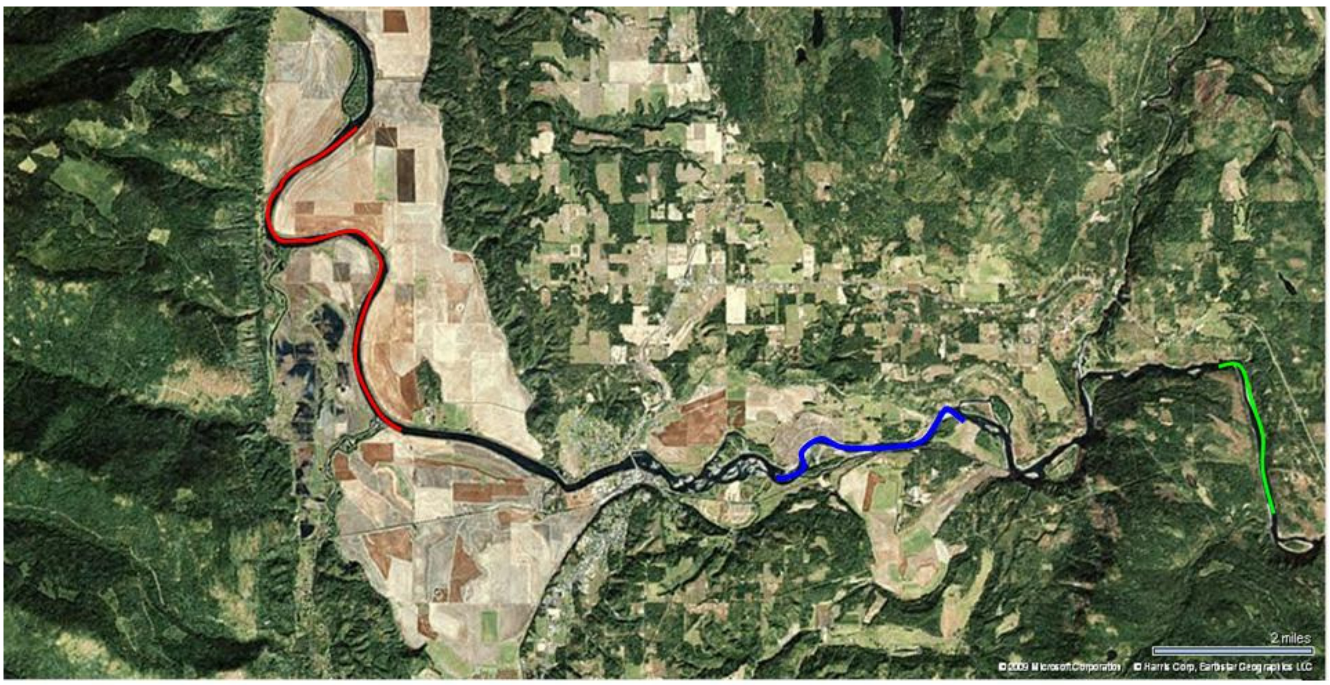
QinetiQ has recently provided two river drifters that will be deployed with NPS drifters. We will evaluate the performance of the QinetiQ drifters. The initial deployments indicate that QinetiQ drifter behaves qualitatively similar (Figure 2) to the NPS drifter, but with less riverbank debris snags. Though, it still gets occasionally snagged. More thorough quantitative evaluations of the QinetiQ will be performed in the fall.

Drifters were released successfully in clusters or in a linear across-channel array of 18-20 drifters in the Kootenai River system. Once released, the drifters were allowed to migrate freely until they exited the area of interest or the memory was filled (approximately 7.5 hours), where they were removed from the water. Drifters were then re-released upstream or in a new location. Drifters would get caught occasionally along the channels.



Kootenai River drifter experiment reaches. 6 Releases were conducted over three days on three reaches of the Kootenai River. Map scale is in the lower right.

DATE:	Time (local/GMT):	Rmks:
Day #1: 26Aug09	0925-1700/1625-0000	Two cluster releases of 17 drifters in the same location as a USGS dye study (red line).
Day #2: 27Aug09	0621-1315/1321-2015	One line abreast release of 15 drifters in the same location as a USGS dye study (red line).
Day #2: 27Aug09	1423-1625/2123-2325	One cluster release of 16 drifters on the braid reach (blue line).
Day #3: 28Aug09	0827-1019/1527-1719	Two cluster releases of 13 and 14 respectively in the canyon reach (bright green line).

Figure 1. Map of the Kootenai River, ID and drifter releases.

Figure 2. Picture of river drifter deployment on the Kootenai River (red line in Figure 1). QinetiQ drifters are pink balls and NPS drifters are pink rods.

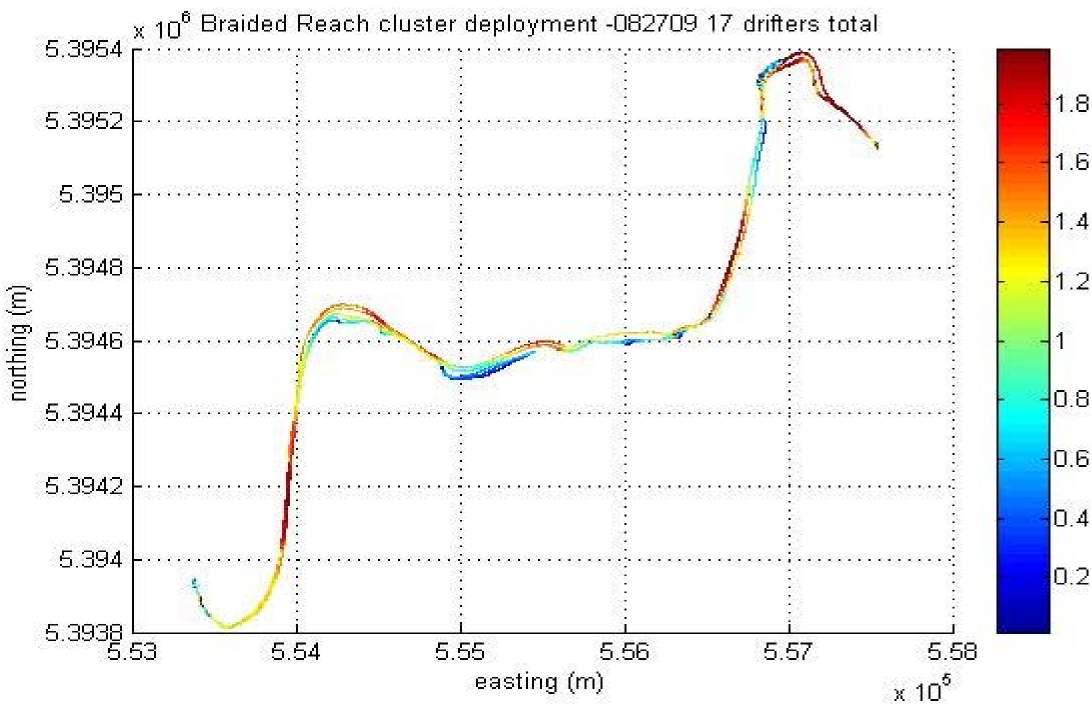


Figure 3. Spaghetti speed drifter tracks for the Kootenai River (blue line in Figure 1). Speed colorbar (m/s) is plotted to the right.

RESULTS

Drifters were deployed in the Kootenai River in late August so the data are still being quality controlled. Preliminary spaghetti speed drifter tracks for the braided reach are shown in Figure 3. The flow rapidly accelerates and decelerates over this reach, which is hypothesized to be controlled by the river morphology. Jon Nelson at the USGS will provided bathymetric information. Bill Swick from the Naval Postgraduate School will use this data as part of his dissertation.

The follow section describes results from last years Skagit River, WA drifter deployments. The time series of drifter positions were quality-controlled by removing erroneous points that exceeded three velocity standard deviations. Time gaps in the data were interpolated with a spline algorithm for gaps less than 10 seconds and a linear algorithm for gaps greater than 10 seconds. A 102 second moving average was required to smooth the river data before coordinate transformation. We transformed the geographic coordinate frame to local river coordinate frame (s,n) as outlined by Legleiter and Kyriadkidis (2007). The accuracy and precision of the coordinate transform is primarily a function of curvature and discretization of the centerline. Errors associated with the transformation are O(cm) (Legleiter and Kyriadkidis, 2007) [Figure 4].

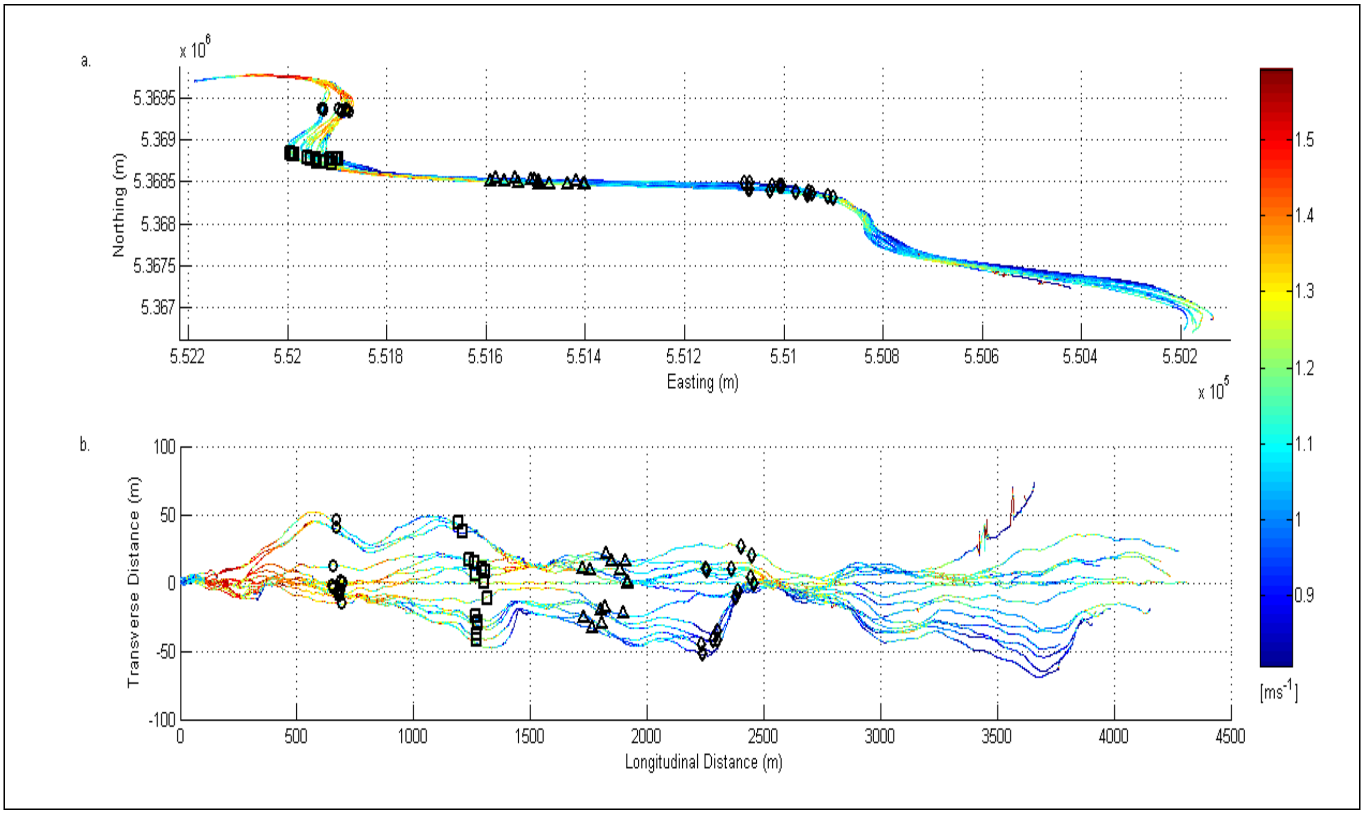


Figure 4: Upper Skagit drifter speed colorline tracks for the (a) geographic coordinate frame, and (b) the river-fitted local coordinate frame utilizing Legleiter and Kyriadkidis (2007) technique. Symbols represent the position of the drifters at 500 (circle), 1000 (square), 1500 ((triangle) and 2000 (diamond) seconds after release. Speed colorbar plotted on the right.

Spatial binning the drifter observations is required to properly describe the Eulerian flow field. However, there is a compromise between the spatial resolution, bin size, and statistical confidence. Five or more independent observations are required within a bin to be statistically significant (Spydell et al., 2007). The number of independent observations, known as degrees of freedom (DOF), in a bin is determined by the total time that the drifters occupy a bin divided by the Lagrangian decorrelation time, T_L, given by:

$$DOF_{bin} = \frac{\sum_{j=1}^{N} t_i}{T_L} \quad (1)$$

where DOF_{bin} is degrees of freedom for each bin, j denotes each individual drifter and t_i is the time each drifter spent inside an individual bin. T_L represents fluid particle memory and describes the time scale of the longest fluctuation. Therefore, a priori knowledge of this time is required to adequately select the longitudinal and transverse bin dimensions.

T_L is directly calculated from the ensemble average of the auto covariance function, $C_{ii}(\tau)$, for each drifter concurrently deployed, and is defined as:

$$C_{ii}(\tau) = \left\langle v_i^{'}\left(t'=0\right) v_i^{'}\left(t'=\tau\right)\right\rangle \quad (2)$$

where $v^{'}$ is the anomalous drifter velocity which is calculated by removing the ensemble mean velocity from each individual drifter velocity time series, t' is a relative time step which allows displacement calculations for each drifter for all arbitrary starting positions, i denotes the respective local coordinate direction (s, n), and the angle brackets denote averaging over all drifters for each time lag, τ. Autocorrelation is the auto covariance divided by the covariance. The integral temporal scale is computed by integrating the autocorrelation function over all time lags. Once T_L is determined, the proper bin size is selected to ensure statistical confidence. T_L estimates from Skagit are approximately 3 minutes respectively. Therefore, 15 minutes (900 seconds) of drifter data with each bin is required to obtain the minimum 5 DOF to be statistically confident. For example, a mean river velocity of 1 ms^{-1} requires 5 drifters to occupy a bin that is 180 m long or 10 drifters to occupy a bin that is 90 m long for statistically significant results. This is highly dependent upon the fluctuations in the river, the number of drifters deployed, and the mean river velocity. We are currently evaluating different methods of estimating $T_{L.}$

An evenly distributed release of drifters is believed to provide the best scenario of measuring the transverse flow field, whereas, a cluster release in the center of the channel would provide the highest longitudinal resolution, with the added benefit of allowing relative dispersion estimates. However, this is not necessarily the case. Transverse movement and distribution of the drifters is strongly controlled by river meanders. For that reason, despite deploying in the optimal line abreast configuration, uneven transverse coverage would still remain. In the apex of bends the drifters tend to converge to the outer edge of the channel, limiting the transverse coverage, as observed during the line abreast release in the Northfork (Fig 5b,d). Longitudinal bin size of 250 m was needed to attain four to five transverse bins, spanning ~60 m, with greater than 5 DOF. In contrast, the cluster release (Fig 5a,c) had two transverse bins, separated by the centerline, using a finer longitudinal bin of 70 m. Although the cluster release provides large DOF for each bin (as high as 13), the transverse resolution could not be increased. In the line abreast case, increasing the longitudinal resolution did not ensure transverse coverage throughout the deployment. Once the drifters converged into the sweeping bend the mean speed calculations ultimately became confined to only the outer bin (Fig 5d).

Swick and MacMahan are presenting the use of the use of position-tracking drifters in riverine environments at the IEEE Ocean conference.

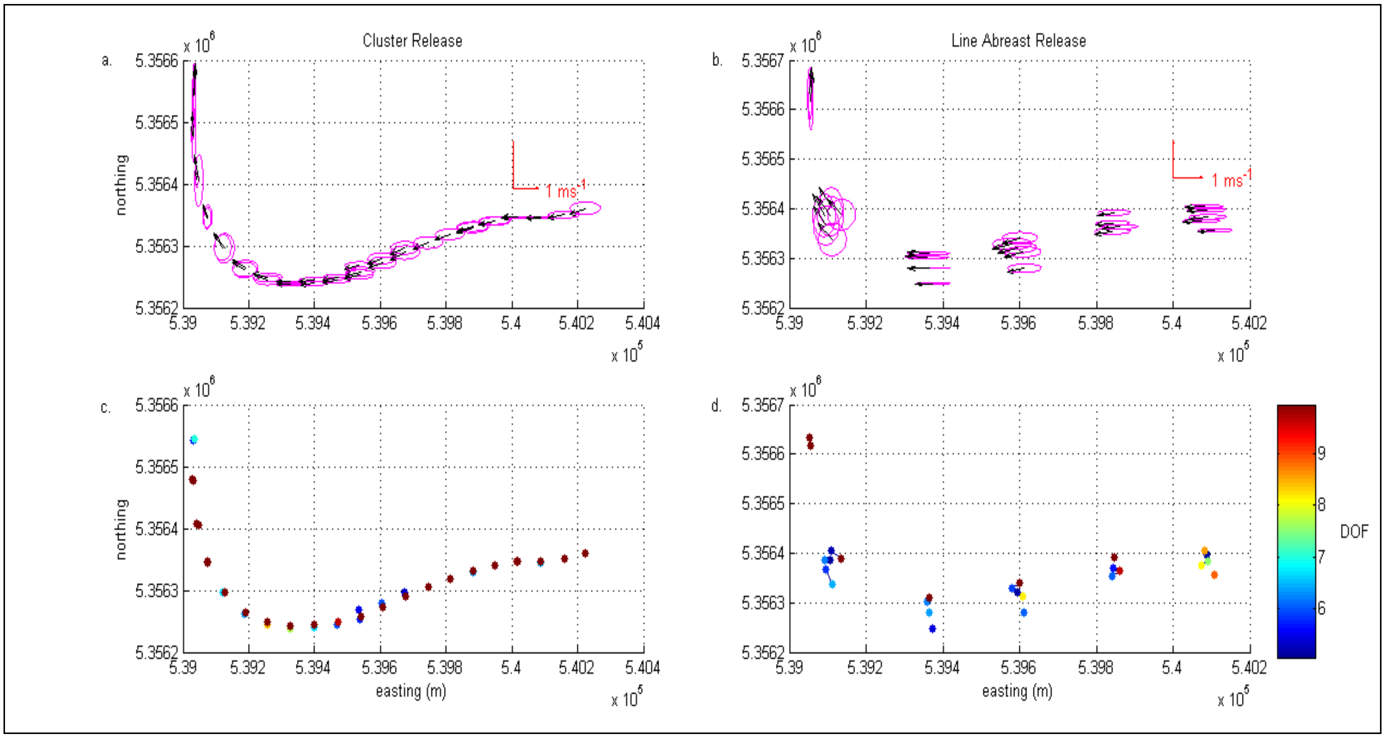


Figure 5. Plan view of spatially-binned mean velocities and fluctuation ellipses (a,b) for Northfork cluster (left) and line abreast releases (right) . The DOF in each bin are plotted in color with scale to the right (c,d); only bins with greater than 5 DOF are shown. The red vector (a,b) provides a speed scale.

IMPACT/APPLICATIONS

The GPS-equipped river drifters provide both Eulerian and Lagrangian observations and fill the observational gaps left by traditional longitudinal tracer methods, and particular transverse mixing (Fischer et al., 1979). GPS-equipped drifters measure a surface flow spatial and temporal scales, for which the decorrelation times can be directly calculated. River studies can be performed at minimal cost and logistical preparation with the GPS-equipped river drifters, as they are inexpensive, easy to deploy, and provide high temporal and spatial resolution data providing new insights into river kinematics. These new observations will be evaluated with Delft FLOW by Ad Reniers and other interested modelers.

RELATED PROJECTS

The GPS-equipped drifters were deployed at Skagit Tidal Flat between September 23-28, 2008. The drifter data were used to evaluate Arete Asscoiates AROSS system velocity measurements. The drifter data were evaluated with Delft FLOW by Dr. Hibler.

MacMahan was awarded an ONR DURIP. The purchase of this equipment will be used in riverine environments.

MacMahan and Swick presented drifter results at the DRI Tidal Flat workshop in San Francisco, 2009 as part of the Fall AGU meeting.

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